BITS PILANI DUBAI CAMPUS
EA C422 – FIBER OPTICS AND OPTOELECTRONICS

II SEMESTER 2012 – 13 **COMPREHENSIVE EXAMINATION** **2 June 2013**

Total Marks : 80 Weightage: 40% Time Allowed: 3 hours

INSTRUCTIONS: This paper contains **ELEVEN (11)** questions and comprises **FOUR (4)** pages. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings.

Q1: A step index fiber operates at a wavelength of 1.55 μm. The core refractive index is 1.48 and the relative refractive index difference is 1%. The diameter of the core needed to make the total dispersion zero is found to be 5 μm. Determine the amount of material dispersion contributed by the fiber at the operating wavelength. At what wavelength is the material dispersion zero for this fiber?
Assume suitable empirical approximation for the contribution due to waveguide dispersion.

(10 marks)

Q2. A graded index optical fiber (Fiber A) with core dia 60 μm, cladding dia 125 μm and profile parameter of 2.1 is joined with another GI fiber (Fiber B) with core dia 75 μm, cladding dia 125 μm and unknown profile parameter α_2. The NA of the fibers A and B are 0.25 and 0.21 respectively. The fiber axes are perfectly aligned and there is no air gap. If the total insertion loss for transmission in the forward direction (A to B) is 5 dB, calculate the profile parameter α_2. What is the insertion loss for transmission in the backward direction (B to A)?

(10 marks)

Q3: (i) Explain why single mode fibers have a much lower core diameter compared to their multimode counterparts for a given wavelength of propagation?

(ii) Differentiate between Mode field Diameter and Peterman 2-spot size. A typical step index fiber has a mode field radius of 4.9 μm and a normalized frequency parameter of 2.186 for a certain wavelength of propagation. Determine the Peterman radius.

(8 marks)

Q4.

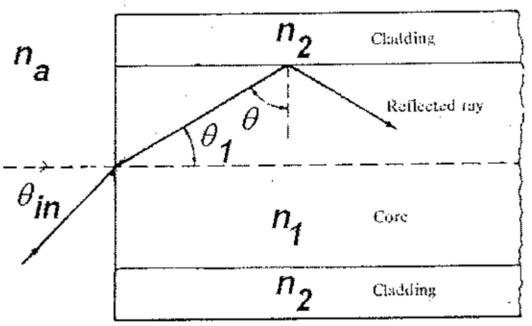


Figure 1

In a step index fiber shown in Figure 1, the maximum value of the angle θ_{in} for light to be guided through the core is 14.1°. The diameter of the core is 100 μm. The fiber is placed in air. The critical angle at the core cladding interface is 80.6°. (a) Determine the refractive indices n_1, n_2 of the core and cladding layers. (b) What is the pulse broadening per unit length due to multipath dispersion for this fiber? (c) Estimate the maximum number of total internal reflections per unit length for rays guided by this fiber?

(8 marks)

Q5. A certain photodiode provides an output photocurrent of 1.5 μA for an input optical power of 4 μW at a wavelength of 1.55 μm. If 4 x 10^{10} photons at a wavelength of 1.55 μm are incident on the photodiode per second, at what rate are the electrons collected at the detector terminals?

(4 marks)

Q6 The bandgap of InAs is 0.36 eV and that of GaAs is 1.43 eV. Determine the exact composition of a ternary compound material $In_xGa_{1-x}As$ that would enable it to be used as an optoelectronic source emitting at 1550 nm. What are the drawbacks of using a ternary compound for the active region in a p-n junction optoelectronic source.

(6 marks)

Q7. The power p(t) of light arriving at the receiving end of an optical fiber is a function of time t, is found to be Gaussian, centered around t = 0 with a peak value of p_o. The FWHM of the pulse is $2\sqrt{\ln 2}$.

(a) Write down the expressions for p(t) in the range $-\infty < t \leq \infty$

(b) Calculate that the energy associated with the pulse.

(8 marks)

Q8. Draw the electric field distribution in both the core and cladding layers for a mode represented by m = 3 in a planar waveguide. What is the nature of the electric field in the core and cladding?

(5 marks)

Q9. A fiber optic link requires two connectors, one at the transmitting end and another at the receiving end. The loss at each connector is 1 dB and each splicing accounts for a 0.5 dB loss. The link of total length 40 km has splices after every 3 km length of fiber. The fiber cable has the following specifications: cable loss $\alpha_f = 0.5$ dB/km, $(\Delta T)_{intramodal} = 3$ ns/km, $(\Delta T)_{intermodal} =$ 1 ns/km. The source, along with its drive circuit, has a rise time of 12 ns, while the receiver has a rise time of 11 ns. A safety margin of 10 dB is also required to be maintained, to overcome any other unforeseen losses. (a) If the minimum power supplied by the optical source at the transmitting end is 1 μW, determine the minimum optical power required for a photo detector to detect at the receiving end. (b) What is the maximum data transmission rate possible, using the RZ code?

(10 marks)

Q10. Why are Si based p-n junctions not suitable for use as optoelectronic sources?

(4 marks)

Q11. Design a planar rectangular optical waveguide so as to have a maximum guide thickness to allow two modes of propagation at wavelength $\lambda = 1.31\ \mu m$. The critical angle for the guide – cladding interface is 80°. The guide refractive index is 1.5. If the wavelength is reduced to 0.9 μm, how many modes can the guide support now? Use Figure 2.

(7 marks)

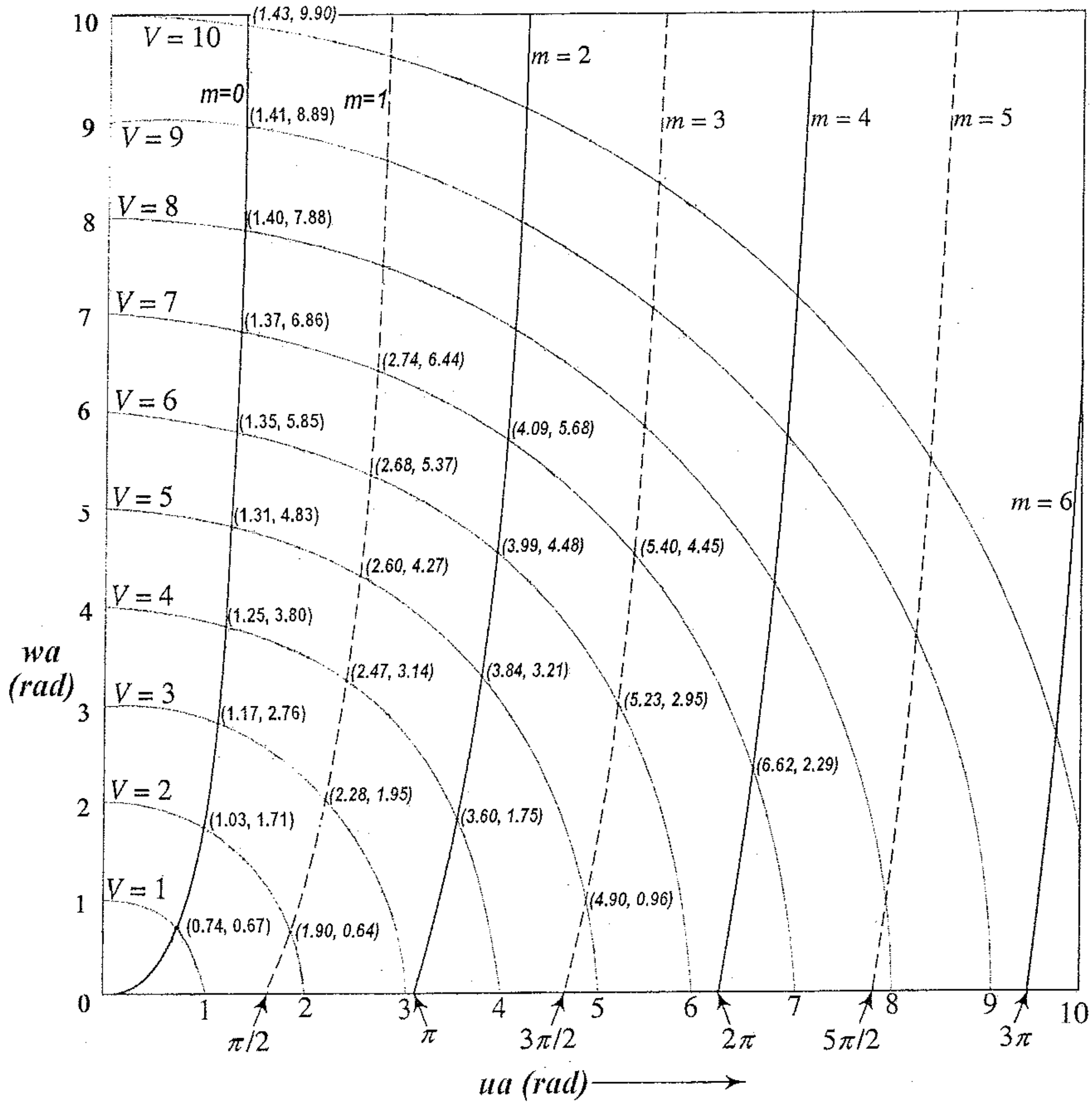


Figure 2

TABLE OF SELECTED CONSTANTS

Parameter	Symbol	Value	Units
Electronic Charge	q	1.6×10^{-19}	C
Boltzmann's constant	k or k_B	1.38×10^{-23}	J/K
Permittivity of free space	ε_o	8.85×10^{-14}	F/cm
Dielectric constant of Si (ε_r)	ε_{Si}	11.7	-
Speed of light	c	3×10^8	m/s
Plank's constant	h	6.624×10^{-34}	J.s
Bandgap of Si	E_g	1.12	eV

End of Paper

EAC 422 FODE Compre Exam

Sem 2, 2012-2013 Marking Scheme.

Q1 $D = D_w + D_m = 0 \Rightarrow D_m = -D_w$.

$$D_w = \frac{-n_2 \Delta}{c\lambda}\left[0.08 + 0.549(2.834 - V)^2\right]$$

$V = \frac{2\pi a}{\lambda} \cdot n_1\sqrt{2\Delta}$;

$2a = 5\,\mu m$, $\lambda = 1.55\,\mu m$, $n_1 = 1.48$, $\Delta = 0.01$

Substituting, $V = 2.1212$ ——— (4)

~~D_w~~ Also $n_2 = n_1\sqrt{1-2\Delta} = 1.4651$

Hence $D_w = -11.309\ ps\ km^{-1}\ nm^{-1}$

The material dispersion required $D_m = +11.309\ ps\ km^{-1}\ nm^{-1}$ — (4)

The wavelength at which material dispersion is zero is obtained from $D_m = 122\left(1 - \frac{\lambda_{ZD}}{\lambda}\right)$

with $D_m = +11.309\ ps\ km^{-1}\ nm^{-1}$ when $\lambda = 1.55\,\mu m$.

Substituting, $\lambda_{ZD} = 1.406\,\mu m$ ——— (2)

Q2 For fiber A → $cd_1 = 60\,\mu m$, $\alpha_1 = 2.1$, $NA_1 = 0.25$

for fiber B → $cd_2 = 75\,\mu m$, $\alpha_2 = ?$, $NA_2 = 0.21$

No air gap, no misalignment.

From A → B $\eta_{cd} = 1$ since $cd_2 > cd_1$

$\eta_{NA} = \left(\frac{NA_2}{NA_1}\right)^2 = 0.7056$

$\eta_\alpha = ?$

The overall loss $\eta_{dB} = 5$ dB

$$-10 \log_{10}(\eta) = 5 \Rightarrow \eta = 0.31622$$

$$0.31622 = \eta_{cd} \times \eta_{NA} \times \eta_{\alpha} \Rightarrow \eta_{\alpha} = 0.4481$$

$$0.4481 = \frac{1 + 2/\alpha_1}{1 + 2/\alpha_2} \Rightarrow \boxed{\alpha_2 = 0.496} \quad — (5)$$

$$\alpha_1 > \alpha_2$$

For the backward direction $B \rightarrow A$,

$$\eta_{cd} = \left(\frac{0.60}{0.75}\right)^2 = 0.64$$

$$\eta_{NA} = 1 \quad \text{and} \quad \eta_{\alpha} = 1 \quad (\text{Since } \alpha_1 > \alpha_2)$$

Hence Overall coupling efficiency

$$\eta = 0.64 \quad \text{or} \quad -10 \log_{10}(0.64) = 1.938 \text{ dB}$$

— (5)

Q3 i a) For single mode fiber, freq. parameter V in rectangular guide is less than $\pi/2$.
For multimode, larger values of V are allowed.

$$V = \frac{2\pi}{\lambda} a \cdot (NA)$$

If λ is fixed and NA is fixed then lower V means lower core thickness. Thus SMF have much lower core thickness than multimode fibers — (2)

i b) Differentiate — (2)

$$MFD = 2W = 2a\left[0.65 + \frac{1.619}{V^{3/2}} + \frac{2.879}{V^6}\right]$$

$$(MFD)_p = 2W_p = 2W - 2a\left[0.016 + \frac{1.567}{V^7}\right]$$

$$= 2a\left[0.634 + \frac{1.619}{V^{3/2}} + \frac{2.879}{V^6} - \frac{1.567}{V^7}\right]$$

If $\omega = 4.9\,\mu m$, $V = 2.186$, then from equation for MFD,

$$a = 4.162\,\mu m$$

Hence $\omega_p = 4.806\,\mu m$ — (4)

Q4. When $\theta_{in} = \theta_{max} = 14.1°$,

$\theta = \theta_c \Rightarrow n_1 \sin\theta_c = n_2 \sin 90°$.

$\theta_1 = 90 - \theta_c$

a) $n_a \sin 14.1° = n_1 \sin(90 - \theta_c) = n_1 \cos\theta_c$

$n_a = 1$, hence $n_1 = 1.4916$

$\theta_c = 80.6°$,

$n_2 = n_1 \sin\theta_c = 1.47156$ — (4)

b) pulse broadening per unit length

$$\frac{\Delta T}{L} = \frac{n_1}{n_2}\left(\frac{n_1 - n_2}{c}\right) = 6.771 \times 10^{-11}\ s\,m^{-1}$$ — (2)

c) Max. no. of reflections / meter

$$= \frac{\tan\theta_1}{2a} = \frac{\tan 9.4}{100 \times 10^{-6}}\ m^{-1}$$

$$= 1655\ m^{-1}$$ — (2)

Q5 Responsivity $R = \frac{I_p}{P_{in}} = \frac{1.5}{4} AW^{-1} = 0.375 AW^{-1}$

Also $R = \frac{\eta e \lambda}{hc} \Rightarrow \eta = \frac{Rhc}{e\lambda}$

$h = 6.624 \times 10^{-34}$ J.s $c = 3 \times 10^8$ m/s, $e = 1.6 \times 10^{-19}$ coul

$\lambda = 1.55 \times 10^{-6}$ m

Substituting, $\eta = 0.3 = \frac{r_e}{r_{ph}}$.

Rate at which ~~pot~~ photons are ~~...~~ incident, $r_{ph} = 4 \times 10^{10}$ s^{-1}

Rate at which electrons are collected

$= r_e = r_{ph} \times \eta = \underline{1.2 \times 10^{10}\ s^{-1}}$ — (4)

Q6 $E_g(InAs) = 0.36$ eV ; $E_g(GaAs) = 1.43$ eV

$E_g(In_x Ga_{1-x} As) = x \cdot [E_g(InAs)] + (1-x) \cdot [E_g(GaAs)]$

$= 0.36x + (1-x)(1.43)$

$= 1.43 - 1.07x$.

For LED operating at 1550 nm.

$E_g = \frac{hc}{\lambda} = 0.8013$ eV $= 1.43 - 1.07x$

Solving $x = 0.5875$

Exact comp. of ternary is ~~Eg(1550)~~ $In_{0.5875} Ga_{0.4125} As$ — (4)

Drawbacks: Lattice Mismatch

dislocation type defects at interface

low efficiency — (2)

Q7

Gaussian profile, hence

$$p(t) = p(0) \cdot e^{-bt^2}$$

a) According to question,

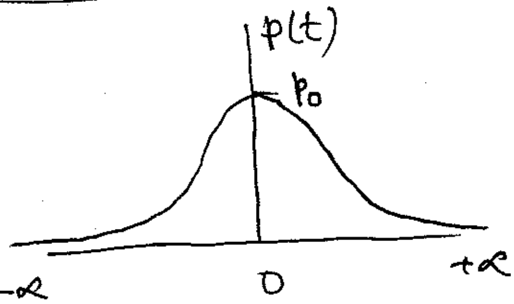
$p(0) = p_0$ and for FWHM, $p(t_1) = p_0/2$

$$\frac{p_0}{2} = p_0 \, e^{-bt_1^2} \Rightarrow t_1 = \pm \frac{1}{\sqrt{b}} \sqrt{\ln 2}$$

$$\text{FWHM} = \frac{2}{\sqrt{b}} \sqrt{\ln 2} = 2\sqrt{\ln 2} \text{ (by question)}$$

Hence $b = 1 \Rightarrow$ $\boxed{p(t) = p_0 \, e^{-t^2}}$ — (4)

b) $$\mathcal{E} = \int_{-\infty}^{\infty} p(t)\, dt$$



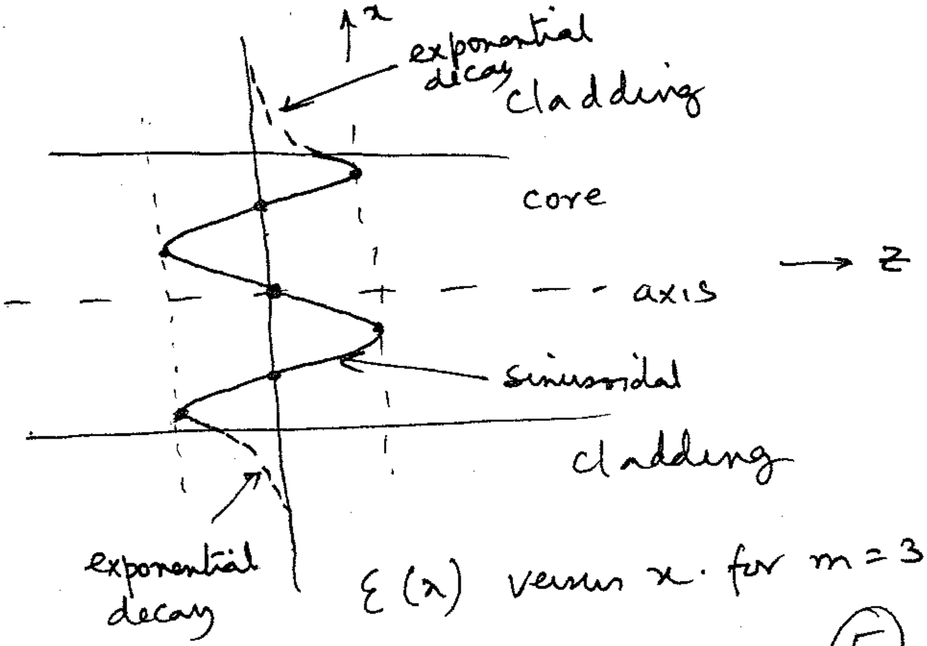
Since symmetrical Gaussian

$$\mathcal{E} = 2 \int_0^{\infty} p(t)\, dt$$

$$= 2 \int_0^{\infty} p_0 e^{-t^2} dt = 2p_0 \left(\frac{\sqrt{\pi}}{2}\right) \cdot \frac{2}{\sqrt{\pi}} \int_0^{\infty} e^{-t^2} dt$$

$$= p_0 \cdot \sqrt{\pi} \cdot \text{erf}(\infty) = p_0 \cdot \sqrt{\pi} = \underline{\underline{1.772\, p_0}}.$$ — (4)

Q8



$\mathcal{E}(x)$ versus x. for $m = 3$.

(5)

Q9 (a) Total channel loss C_L

$$C_L = 2 \times 1\,dB + 13 \times 0.5\,dB + 40 \times 0.5\,dB = 28.5\,dB$$

- $2 \times 1\,dB$ → loss due to 2 connectors
- $13 \times 0.5\,dB$ → loss due to 13 splices
- $40 \times 0.5\,dB$ → loss due to cable length

$P_{tx} = 1\,\mu W \Rightarrow 10 \log 1 \times 10^{-6} = -60\,dBm$.

For minimum detectable power,

$$P_{rx} + C_L + 10 = P_{tx} = -60$$

$$\Rightarrow P_{rx} = -98.5\,dBm.$$

$$= 10 \log P_{rx} \Longrightarrow P_{rx} = 0.141\,nW.$$

Minimum power required for photo detector to detect $= 0.141\,nW$.

(5)

.9 (b)

$$t_{sys}^2 = t_{tx}^2 + t_{intermodal}^2 + t_{intramodal}^2 + t_{rx}^2$$

$$= 12^2 + 120^2 + 40^2 + 11^2$$

$$t_{sys} = 127.53 \text{ ns}.$$

With RZ format, limiting value of t_{sys}

$$t_{sys} = \frac{0.35}{B} \Rightarrow B = 2.744 \text{ M bits/sec.}$$

The max. data transmission rate possible = 2.744 Mbits/s — (5)

Q10 Si is indirect band gap semiconductor. For optoelectronic source, p-n jn. device must be of direct band gap material, where E-k diagram has E_c minimum and E_v maximum at the same value of k. So e-h recombination results in the emission of photons. In Si, e-h recombination is mostly with emission of phonons (lattice vibration) resulting in heat. So such devices will be very poor optoelectronic sources — (4)

Q 11

$V = \frac{2\pi a}{\lambda}(NA)$ $\theta_c = 80^\circ$, $n_1 = 1.5$, $\lambda = 1.31\,\mu m$

$n_2 \sin 90 = n_1 \sin 80^\circ \Rightarrow n_2 = 1.477$

$NA = \sqrt{n_1^2 - n_2^2} = 0.26$

For 2 modes to operate, the frequence parameter

$V < \pi$ $V = \frac{2\pi a}{\lambda}(NA)$

Hence limiting value of 2a is

$2a < \frac{\pi \lambda}{\pi (NA)}$ or $\boxed{2a < 5.038\,\mu m.}$

Limiting value $2a = 5.038\,\mu m.$

Design ; $2a = 5.038$ (guide thickness)
$n_1 = 1.5$ (core refractive index)
$n_2 = 1.477$ (cladding refractive index) — (4)

If $\lambda = 0.9\,\mu m$, now, then

$V = \frac{5.038 \times \pi \times 0.26}{0.9} = 4.57$

Thus $V > \pi$ and $< 3\pi/2$

So the V graph intersects at 3 points.
3 modes of propagation are now possible. — (3)

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SECOND SEMESTER 2012 – 2013 TEST – 2 OPEN BOOK

YEAR IV ELECTIVE (EEE / EIE)

Course Code: EA C422
Course Title: Fiber Optics and Optoelectronics
Duration : 50 minutes

Max Marks: 40
Weightage: 20%

INSTRUCTIONS: Answer ALL questions. All symbols have their usual significance

1. Compare the emitted power characteristics of a typical SLED with an ELED and explain why SLED can have a superior performance over ELED. What advantages would an ELED have over SLED?

(5 marks)

2. The bandgap of GaAs and InAs at 300 K are 1.43 eV and 0.36 eV respectively. Assuming Vegard's law, express the band gap of the ternary compound $In_xGa_{1-x}As$ as a function of In mole fraction x. What composition x of $In_xGa_{1-x}As$ would provide an optoelectronic source emitting light at 1300 nm? What are the advantages of an LED constructed using this principle?

(7 marks)

3. A Si p-n photodiode is connected to a measuring circuit shown in Figure 1. The battery voltage is 10V. Resistance R = 5 KΩ. An incident light at wavelength 1.55 μm provides an input optical power on the photodiode of 10 μW. Under this condition, the voltmeter measures 50 mV.

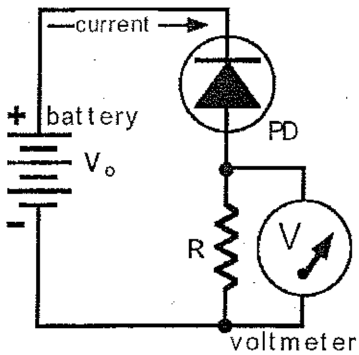

Figure 1

(i) Determine the Responsivity R and the quantum efficiency η of the photodiode.

(ii) If the photodiode has n- and p- regions equally doped to a level of 10^{16} cm^{-3}, determine the depletion region width W where most of the incident optical power is absorbed. Assume T = 300 K, n_i = 10^{10} cm^{-3}. Dielectric constant of Si = 11.7, permittivity of free space = 8.854 x 10^{-14} F/cm, electron charge q = 1.6x10^{-19} Coulomb.

(10 marks)

4. Why is there a long wavelength cut off in the response of a photodiode above which photons are not absorbed by the semiconductor? Draw a typical responsivity characteristics of ideal and practical photodiode and explain any difference in their characteristics. How can the quantum efficiency of a practical photodiode be improved?

(6 marks)

5 A certain photodiode has a responsivity R at a wavelength λ. An optoelectronic source as described in Q2 is incident on the photodiode with an optical power of 5 μW. Determine the quantum efficiency of the photodiode that is needed to provide a photocurrent of 2 μA. If due to some reason the quantum efficiency decreases by 10 %, what input optical power will be needed to maintain the same output photocurrent?

(6 marks)

6. Draw the band diagram of a light emitting diode which is biased in a manner that it is able to emit radiation. Mark the conduction bands, valence bands, Fermi levels and the depletion region edges in the diagram.

[6 marks]

END OF PAPER

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Supplementary Answer Sheet

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Supplementary sheet No. ______

ID No. ______ Name ______

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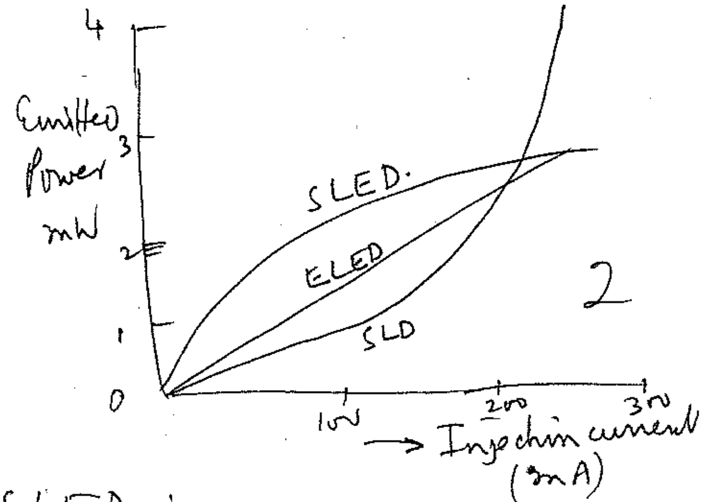
EA C 422 Test 2 Sem2 2012-13 Marking Scheme



Q1.

At low injection currents, the heat generated by device is quickly conducted away by heatsink + emission from entire surface makes it more efficient than ELED. 2

2

The advantage of ELED with SLED is that the ELED has low divergence in vertical direction. This make it more efficient to couple with optical fiber. Stripe geometry ELEDs based on InP/InGaAsP give improved design for coupling of ~~sm~~ SMF. 1

Q2 $E_g(In_xGa_{1-x}As) = x \times [E_g(InAs)] + (1-x) \cdot [E_g(GaAs)]$

$= x \times 0.36 + (1-x) \times 1.43$

$\boxed{E_g(x) = 1.43 - 1.07x}$ 2

To emit at 1.3 μm, $E_g = \frac{hc}{\lambda} = \frac{1.24}{1.3}$ eV $= 0.9538$ eV

for which the required molefraction is $x = \frac{1.43 - 0.9538}{1.07}$

$= 0.445$

Required composition = $In_{0.445}Ga_{0.555}As$ 3

Advantages: Band gap engineering continuously tunable LED source. 1

Disadvantages: matching band gap results in lattice mismatch with substrate for ternary compounds. 1

Q3 i) $V_R = 50\,mV = 0.05\,V$

$R = 5\,k\Omega$

$I_R = \frac{0.05}{5}\,mA = 0.01\,mA = 10\,\mu A = I_{PD}$.

Responsivity $R = \frac{I_p}{P_{in}} = \frac{10\times10^{-6}}{10\,\mu W} = 1\,A/W$. 3

$\eta = \frac{Rhc}{q\lambda} = 0.8$ |

ii) $N_a = N_d = 10^{16}\,cm^{-3}$

$$W = \sqrt{\frac{2\epsilon}{q}\left(\frac{1}{N_a}+\frac{1}{N_a}\right)(V_{bi}+V_{PD})}$$

$$V_{bi} = \frac{KT}{q}\ln\frac{N_aN_d}{n_i^2} = 0.718\,V$$

$V_{PD} = 10\,V - 0.05\,V = 9.95\,V$.

$\epsilon = 8.854\times10^{-14}\times 11.7$ F/cm.

$W = 1.662\,\mu m$. 6

(4) Photons can only be absorbed by photodiode if the absorbed photon energy is able to excite the electrons in the V.B. to move to occupy states in the conduction band for which a minimum energy E_g is required

$E_{ph} \geq E_g$ or $h\nu \geq E_g$

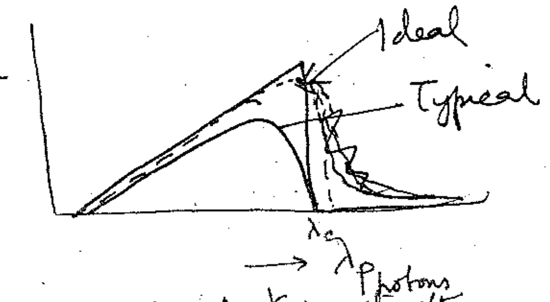
$\frac{hc}{\lambda} \geq E_g$ or $\lambda \leq \frac{hc}{E_g}$ 2

All wavelengths $\leq \frac{hc}{E_g}$ will be absorbed.

The long wavelength cutoff is therefore present $\lambda_c = \frac{hc}{E_g}$.

Above $\lambda_c = \frac{hc}{E_g}$, photons are not absorbed.

The probability of electrons occupying a state close to C.B edge is more than the probability of electrons occupying a state deeper into the C.B. Absorption is more from V.B edge to C.B edge corresponding to E_g than for energies $>> E_g$.



2

To increase η, the Fresnel reflection coefficient R, ~~so~~ must be decreased at the interface where light strikes, and the product αd must be large

$1/\alpha >>$ and $d >>$.

High absorption coefficient for the incident light

width of the region where the absorption takes place must be very large ($W >>$)

(5) In Q2, the source $\lambda = 1300\,nm = 1.3\,\mu m$.

$E_g = 0.9538\,eV$ for the source

$$R = \frac{I_p}{P_{in}} = \frac{2\times10^{-6}\,A}{5\times10^{-6}\,W} = 0.4\,A/W$$

$$R = \frac{\eta e}{h\nu} = \frac{\eta e\lambda}{hc}$$

$$\eta = \frac{Rhc}{e\lambda} = \frac{0.4\times6.626\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times1.3\times10^{-6}}$$

$$= 0.3822$$

4

$$\boxed{\eta = 38.22\%}$$

If η decreased by 10%, $\eta' = 0.9\eta = \underline{0.344}$

Original value of $R = 0.4\,A/W$ will now reduce to $R' = 0.4\times0.9 = 0.36\,A/W$ (Since $R' = \frac{\eta' e}{h\nu} = \frac{0.9\,\eta e}{h\nu} = 0.9\times0.4$)

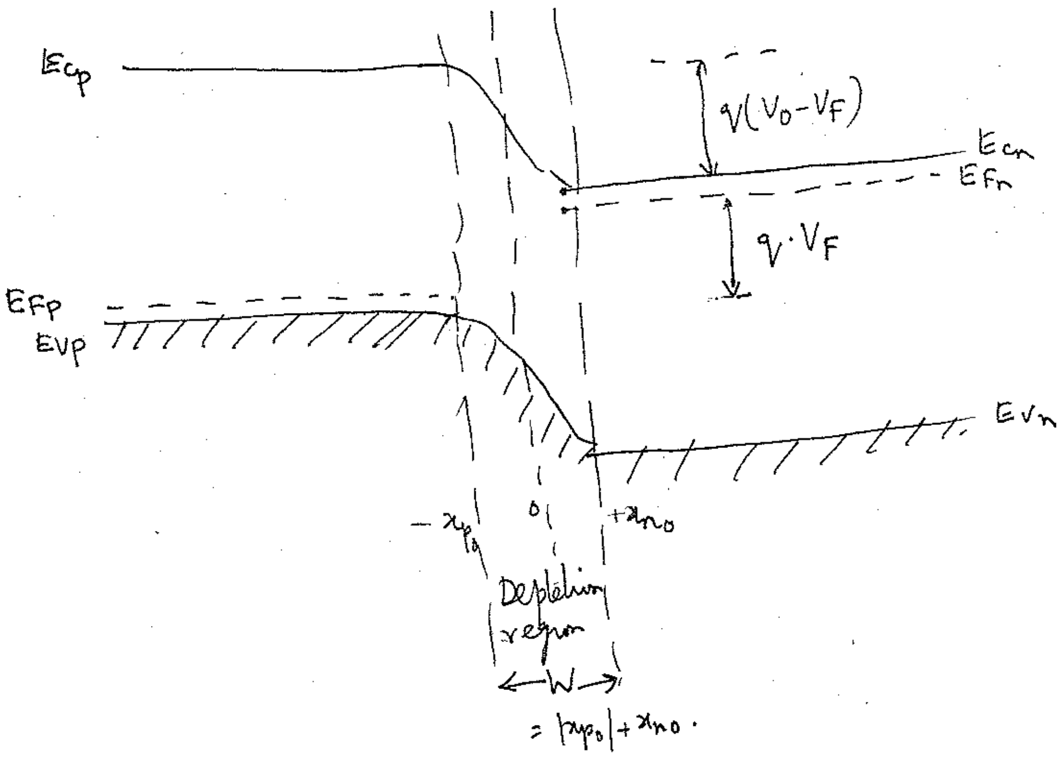
With I_p remaining at $2\,\mu A$,

$$P_{in}' = \frac{2\times10^{-6}}{0.36}\,W = \underline{5.55\,\mu W}$$ of input optical power required

2

(6)

For a simple p^+-n^+ junction forwardbiased,



6

BITS PILANI DUBAI CAMPUS
EA C422 – FIBER OPTICS AND OPTOELECTRONICS - Test 1

Sem2, 2012 2013 | CLOSED BOOK | Time Allowed: 50 mins
Total Marks : 50 | | Weightage: 25%

INSTRUCTIONS

1. This paper contains **SIX (6)** questions and comprises **TWO (2)** pages. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings.

Q1. Draw the electric field distribution in both the core and cladding layers for a mode represented by m = 4 in a planar waveguide.

(6 marks)

Q2. A light pulse has a power distribution p(t) as a function of time t, as shown in Figure 1. The FWHM of the pulse is τ.

(a) Write down the expressions for p(t) in the range $-\Delta T/2 < t \le 0$ and $0 < t \le \Delta T/2$.
(b) Show that the energy associated with the pulse is $p_o.\tau$.
(c) Determine the rms pulse width σ

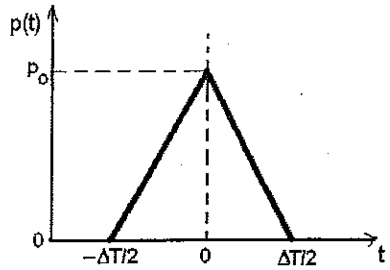


Figure 1

(10 marks)

Q3 A certain planar rectangular optical waveguide of guide thickness 2a and numerical aperture (NA) is used to propagate light at 1.33 μm wavelength. It is found that the frequency parameter V decreases by 1 if the wavelength is increased to 1.55 μm. The same decrease in V is observed if the guide thickness is decreased, with wavelength remaining unchanged at 1.33 μm. By what percentage is the guide thickness decreased?

(10 marks)

Q4. Given that the power confinement factor G for symmetric modes is expressed by

$$\frac{G}{wa(1-G)} = \sec^2(ua) + \frac{\tan(ua)}{ua}$$

G for antisymmetric modes can be obtained by replacing any cos(ua) term by –sin(ua) and sin(ua) by cos(ua) in the above equation.

A planar waveguide is formed from a 6.523 μm thick core film of dielectric material of refractive index 1.50 sandwiched between the cladding slabs of a similar material for which the relative refractive index difference (w.r.t. core) is 0.01324. Calculate the G factors for the modes supported by the waveguide when light of wavelength 1.0 μm is propagating through the waveguide.

(10 marks)

Q5. A single mode rectangular guide has $n_1 = 1.48$, $n_2 = 1.46$ and is designed to guide a light source at 1.55 μm such that ua = 2wa.

Determine the frequency parameter, V. What is the thickness of the guide?

(8 marks)

Q6.

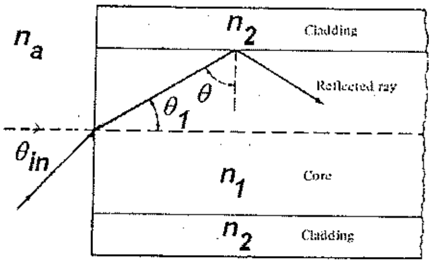


Figure 1

In a step index fiber shown in figure 1, the maximum value of the angle θ_{in} for light to be guided through the core is 14.1°. The fiber is placed in air. The critical angle at the core cladding interface is 80.6°. Determine the refractive indices n_1, n_2 of the core and cladding layers. If the fiber is placed in water, what will be the maximum angle θ_{in} ?. **[6 marks]**

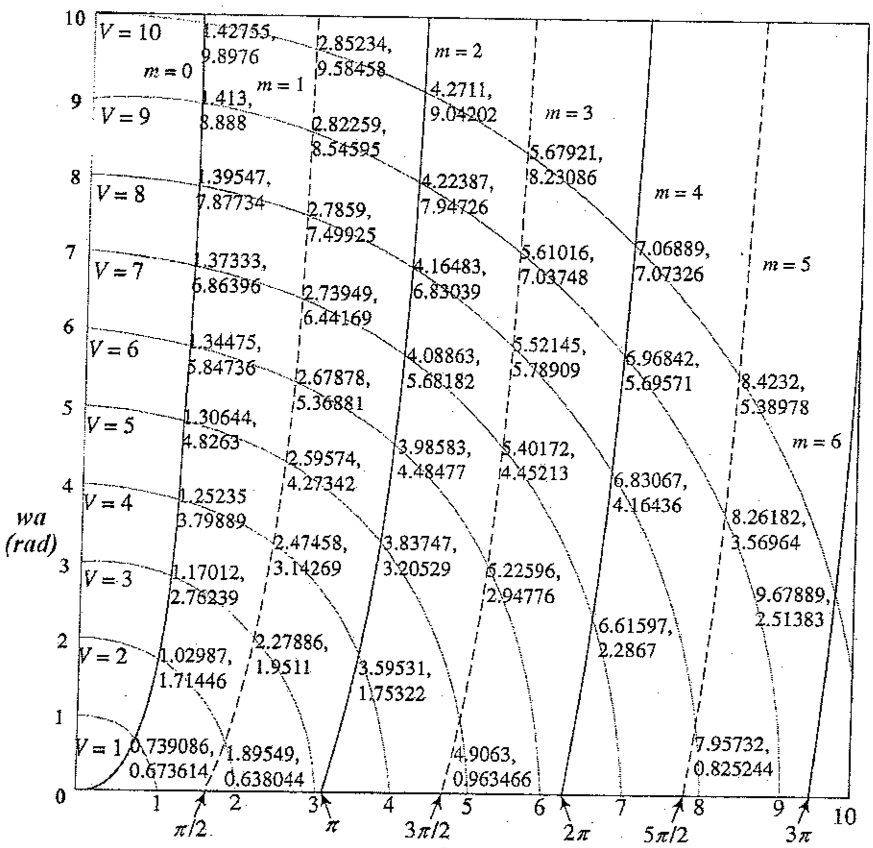


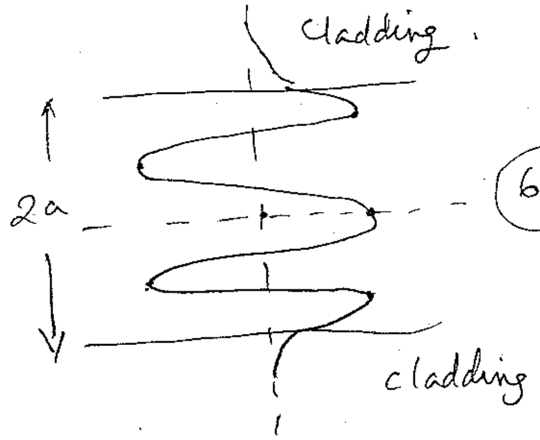
Figure 2

End of Paper

EAC 422 Fiber Optics + Optoelectronics

Test 1 Marking Scheme Sem 2 2012-2013

Q1.



(6M)

Q2 (a) $p(t) = \frac{p_0}{\tau} \cdot t + p_0$ for t between 0 and $-\Delta T/2$

$p(t) = -\frac{p_0}{\tau} \cdot t + p_0$ " " 0 and $+\Delta T/2$.

(2M)

(b) $\mathcal{E} = \int_{-\mathcal{L}}^{\mathcal{L}} p(t)\,dt = p_0 \cdot \tau$ — (4M)

(Show)

(c) $\sigma^2 = \left[\frac{1}{\mathcal{E}}\int t^2 p(t)\,dt - \left[\frac{1}{\mathcal{E}}\int t\,p(t)\,dt\right]^2\right]$ (4M)

$= \tau/2\sqrt{3}$ (Show)

Q3. $V = \frac{2\pi a}{\lambda} \cdot (NA) \quad = \frac{\pi}{1.33} \cdot (2a) \cdot (NA)$.

$V - 1 = \frac{\pi}{1.55} \cdot (2a) \cdot NA \Rightarrow \frac{V}{V-1} = \frac{1.55}{1.33} = 1.1654$

$V = 7.045 \qquad 2a = \frac{7.045 \times 1.33}{\pi (NA)}$ ~~(NA)~~.

(5M)

$(2a)' = \frac{6.045 \times 1.33}{\pi (NA)}$ ~~(NA)~~.

$\frac{2a - (2a)'}{2a} = \frac{7.045 - 6.045}{7.045} = 14.2\%$. (~~7.045 × 1.33~~)

(5M)

Q4. $V = \frac{2\pi a}{\lambda}(NA) = \frac{2\pi a}{\lambda} \cdot n_1 \sqrt{2\Delta}$.

$= \frac{\pi}{1.0} \times 6.523 \times 1.5 \times \sqrt{2 \times 0.01324} = 5$

For mode $m=0$, $\left.\begin{array}{l} wa = 4.82 \\ ua = 1.3 \end{array}\right\}$ (symmetric)

For mode $m=1$, $\left.\begin{array}{l} wa = 4.27 \\ ua = 2.60 \end{array}\right\}$ (antisymmetric)

Mode $m=0$

$$\frac{G}{1-G} = wa \cdot \sec^2(ua) + \frac{wa \tan ua}{ua}.$$

$$= \frac{4.82.}{\cos^2(1.3)} + \left(\frac{4.82}{1.3}\right) \cdot \tan(1.3)$$

$$G = 0.9877$$

(5 M)

Mode $m=1$

$$\frac{G}{1-G} = \frac{wa.}{\sin^2 ua} + \frac{wa \cos ua}{-\sin ua \, (ua)}$$

$$= \frac{wa}{\sin^2 ua} - \frac{wa}{ua \tan ua}$$

$$= \frac{4.27}{\sin^2 2.6} - \frac{4.27}{2.6 \tan 2.6}$$

$$= 18.8$$

(5 M)

$$G = 0.949$$

Q5 Single mode ⇒ $m = 0$, symmetric mode,

$$ua \tan ua = wa = \frac{ua}{2}$$

$$\tan ua = 0.5 \Rightarrow ua = \tan^{-1} 0.5 = 0.4636$$

$$wa = 0.2318$$

$$V = \sqrt{ua^2 + wa^2} = \sqrt{.4636^2 + 0.2318^2} = \underline{\underline{0.518}}$$ (4M)

$$V = \frac{2\pi a}{\lambda} \cdot \sqrt{n_1^2 - n_2^2} \Rightarrow 2a = \frac{V \cdot \lambda}{(2\pi) \cdot \sqrt{n_1^2 - n_2^2}}$$

$$2a = \frac{0.25573}{\sqrt{n_1^2 - n_2^2}} = \underline{\underline{1.0546\ \mu m.}}$$ (4M)

Q6

$$n_a \sin \theta_{in_{max}} = n_1 \sin(90 - \theta_c)$$

$$= n_1 \cos \theta_c.$$

$$n_1 = \frac{\sin 14.1^\circ}{\cos 80.6^\circ} = \underline{\underline{1.5226.}}$$ — (2M)

Also $n_1 \sin 80.6 = n_2 \sin 90^\circ$

$$n_2 = n_1 \sin 80.6 = \underline{\underline{1.5022}}$$ (2M)

If fiber is placed in water, then $n_w = 1.33$.

$$n_w \cdot \sin \theta'_{in_{max}} = \sin 14.1^\circ$$

$$\theta'_{in_{max}} = \underline{\underline{10.55^\circ}}.$$ — (2M)

NAME:--- ID NO: ________________________________

BITS PILANI DUBAI CAMPUS
EA C422 – FIBER OPTICS AND OPTOELECTRONICS - Quiz 2

Sem2, 2012 2013 CLOSED BOOK Time Allowed: 20 mins
Total Marks : 14 Weightage: 7%

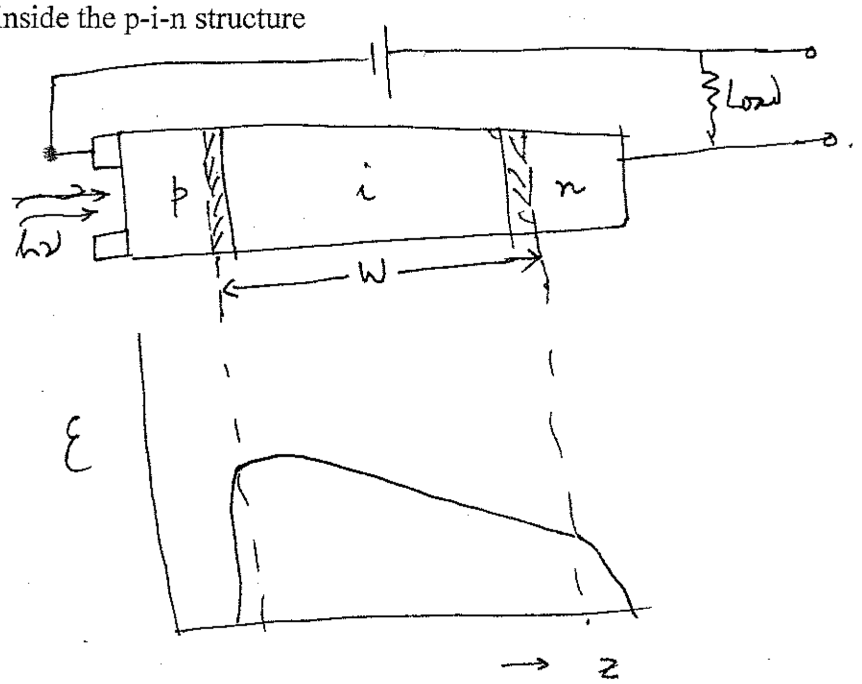
INSTRUCTIONS

Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings.

Q1 (a) Draw a structure of a p-i-n photo diode. Indicate proper biasing of the diode and show how an incident light is detected as an electrical signal across a suitably connected load.

(b) Under the biasing conditions described in part (a), draw the electric field distribution inside the p-i-n structure

[6 marks]



Q2 An Avalanche photo diode has a quantum efficiency of 50% at 1.55 μm wavelength. When illuminated with an optical power of 0.2 μW at this wavelength, it produces an output photocurrent of 5 μA, after avalanche gain. Calculate the multiplication factor of the APD

{3mark}

$$M = \frac{I}{I_p} = \frac{I}{P_{in}R} = \frac{I}{P_{in}\left(\frac{\eta e \lambda}{hc}\right)} = \frac{I \cdot hc}{P_{in}\,\eta e \lambda}$$

$$= \frac{5\times10^{-6} \times 6.626\times10^{-34} \times 3\times10^{8}}{0.2\times10^{-6} \times 0.5 \times 1.6\times10^{-19} \times 1.55\times10^{-6}} = 40$$

NAME:-- ID NO: ____________________

Q3 The response of a longitudinal electro optic modulator is given by $(I/I_o) = \sin^2[(\pi/2)(V/V_\pi)]$ where I is the output intensity for an applied voltage V. I_o is the maximum intensity for an applied voltage V_π. Show that by introducing a quarter wave plate, the intensity of the transmitted beam varies linearly with V. Derive the simplified equation for (I/I_o)

(5 marks)

$$\left(\frac{I}{I_o}\right) = \sin^2\left[\frac{\pi}{2}\cdot\frac{V}{V_\pi}\right]$$

By introducing a $\frac{\lambda}{4}$ plate, there is a total phase shift of $\frac{\pi}{2}$. The 2 ~~each~~ polarized component changes in phase by $\pm\Delta\phi$ where $\Delta\phi = \pi/4$

Thus $$\left(\frac{I}{I_o}\right) = \sin^2\left[\frac{\pi}{4} + \frac{\pi}{2}\cdot\frac{V}{V_\pi}\right]$$

$$= \left[\frac{1}{\sqrt{2}}\cos\frac{\pi}{2}\cdot\frac{V}{V_\pi} + \frac{1}{\sqrt{2}}\sin\frac{\pi}{2}\cdot\frac{V}{V_\pi}\right]^2$$

$$= \frac{1}{2}\left[\cos^2\frac{\pi}{2}\cdot\frac{V}{V_\pi} + \sin^2\frac{\pi}{2}\cdot\frac{V}{V_\pi} + 2\cos\frac{\pi}{2}\cdot\frac{V}{V_\pi}\cdot\sin\frac{\pi}{2}\cdot\frac{V}{V_\pi}\right]$$

$$= \frac{1}{2}\left[1 + 2\cos\frac{\pi}{2}\cdot\frac{V}{V_\pi}\sin\frac{\pi}{2}\cdot\frac{V}{V_\pi}\right]$$

For $V \ll V_\pi$, $\cos\frac{\pi}{2}\cdot\frac{V}{V_\pi} \approx 1$, $\sin\frac{\pi}{2}\cdot\frac{V}{V_\pi} \approx \frac{\pi}{2}\cdot\frac{V}{V_\pi}$.

$$\left(\frac{I}{I_o}\right) \approx \frac{1}{2}\left[1 + 2\cdot\frac{\pi}{2}\cdot\frac{V}{V_\pi}\right] = \frac{1}{2} + \frac{\pi}{2}\cdot\frac{V}{V_\pi}.$$

Thus I varies linearly with V.

The End

NAME:--- ID NO: ______________________________

BITS PILANI DUBAI CAMPUS
EA C422 – FIBER OPTICS AND OPTOELECTRONICS - Quiz 1

Sem2, 2012 2013 CLOSED BOOK Time Allowed: 20 mins
Total Marks : 8 Weightage: 8%

INSTRUCTIONS Answer **ALL** questions.

Q1 What is the difference between propagation phase constant β and the normalized propagation parameter b ? The refractive index of core and cladding layers of a SI fiber are 1.48 and 1.465 respectively. Light of wavelength 0.85 μm is guided through it. Calculate the minimum and maximum values of β. If the diameter of the core is 50 μm, how many modes can be guided?

[3 marks]

Q2 A fiber is having a triangular graded index core with a maximum index or 1.5 along the axis, and a relative refractive index difference of 1.3 %, what diameter of the core is required to guide a single mode only at 1.55 μm wavelength?.

{3 mark}

Q3 Explain the terms Intrinsic and Extrinsic absorption with reference to losses due to material absorption in fibers. If the attenuation in a fiber due to absorption is governed by Beer's Law, write down an expression for the absorption coefficient α. How does Rayleigh's scattering depend on the wavelength?

(2 marks)

EAC 422 - Fiber Optics & Opto Electronics

Quiz 1 Marking Scheme   Sem 2 2012-13

Q 1

$\beta = \frac{2\pi}{\lambda_m}$, λ_m = wavelength in medium

$b = \frac{\beta^2 - \beta_2^2}{\beta_1^2 - \beta_2^2}$, where $\beta_2 < \beta < \beta_1$

$\beta_1 = kn_1$, $\beta_2 = kn_2$ represent limiting values of β.

n_1 = refractive index of core n_2 = r.i. of cladding

$k = 2\pi/\lambda$, λ = wavelength in free space — $1\frac{1}{2}$

Problem: $\beta_1 = \frac{2\pi}{\lambda} \cdot n_1 = 10.93 \times 10^6 \ m^{-1}$

$\beta_2 = \frac{2\pi}{\lambda} n_2 = 10.823 \times 10^6 \ m^{-1}$

$V = \frac{2\pi a}{\lambda} \sqrt{n_1^2 - n_2^2} = 38.82$ — $1\frac{1}{2}$

$M_g = V^2/2 = 753$ modes

— $1/2$

Q2

$V_c = 2.405 \left(1 + \frac{2}{\alpha}\right)^{1/2}$

$\alpha = 1$, $V_c = 4.1655 = \frac{2\pi a}{\lambda} \sqrt{n_0^2 - n_2^2}$ — (1)

$n_0 = 1.5$, $n_c = n_0(1 - \Delta) = 1.4805$ — (1)

$N.A = \sqrt{n_0^2 - n_c^2} = 0.241$

— $1/2$

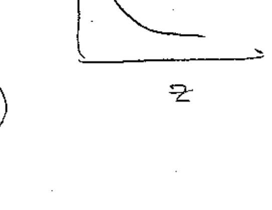
Hence $2a = 8.529 \ \mu m$

— $1/2$

Q3

Explain intrinsic & Extrinsic absorption

Beer's Law: $\frac{dP}{dz} = -\alpha P \Rightarrow P = P_0 e^{-\alpha z}$



$\alpha \ (dB \cdot km^{-1}) = \frac{10}{L(km)} \log_{10} \left(\frac{P_{in}}{P_{out}}\right)$ — (1)

Rayleigh scattering $\propto \lambda^{-4}$ — $1/2$